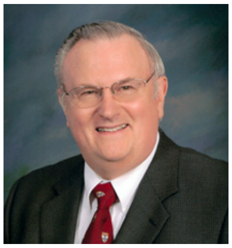
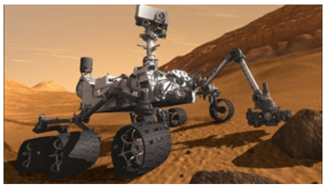
The Boice Report #34



NCRP
National Council on Radiation Protection & Measurements

John D. Boice, Jr., NCRP President
ICRP Main Commissioner
UNSCEAR U.S. Alternate Representative
Vanderbilt Professor of Medicine

Going to Mars Is More Than Curiosity



Two of my favorite pursuits are learning about space exploration and nuclear submarines. The National Aeronautics and Space Administration (NASA) encompasses the human spirit for adventure and knowledge; the nuclear navy is challenged with protecting our freedoms. Both involve extraordinary individuals with extraordinary missions supported by extraordinary teams. Both involve ionizing radiation, more so in going to Mars (Curiosity, pictured at left, is the probe that landed on Mars and included measurements of space radiation along the way) than in going under the sea (last year I went under the sea in a fast attack nuclear submarine). This January, I attended the NASA Human Research Program workshops held in Galveston, Texas, and then I attended the NCRP Scientific Committee (SC) 1-24 meeting on providing guidance to NASA on possible central nervous system (CNS) effects from space radiation. A Mars mission, planned for 2035, would take nearly three years and the astronauts would receive ~200 mGy from a continuous bath of protons and the occasional zingers with heavy ions traveling at high speed (high atomic mass and energy [HZE] particles). The NASA-defined effective dose would be ~900 mSv (received at a rate of ~1 mSv d^{-1}). Radiation is an important and potentially limiting factor in going to Mars, but is only one of many stresses to deal with, including behavioral health and performance issues.

Similarities between astronauts and submariners. NASA uses the term "analogues" to describe situations on Earth that might be similar to long-term space travel. I was struck with the similarities between the nuclear submarine environment and going to Mars. Both crews have to cope with close and constant 24-hour contact with individuals for long periods (a sub may go out for six months; a Mars trek lasts 36 months), limited contact with family and friends, a deadly environment outside the vessel, no 24-hour day/night circadian cycles, no turning back (depending on the submarine mission), no windows to the outside world, low-dose chronic exposures (less so on a nuclear submarine but all sailors wear dosimeters), sleep deprivation, strenuous workloads, reliance on team members, stringent physical and mental requirements to qualify, requirements to be multitalented (skilled) to handle most operational challenges, and potential for carbon dioxide buildup. Stresses that lead to aberrant behavior and diminished abilities can have catastrophic consequences, particularly during an emergency situation. NASA has a comprehensive program to evaluate the effects of space flight stresses on performance and team capabilities. The National Council on Radiation Protection and Measurements (NCRP) is evaluating whether space radiation can exacerbate or add to these stresses through direct or indirect effects on the CNS—not just cognitive dysfunction that might affect the mission but also increased susceptibility to dementia later in life.

Radiation exposures. Nuclear reactors can expose submarine crews to radiation, but protection measures since the days of Rickover have been stringent and sailors' doses on average have been way below occupational limits. In fact, exposure to natural sources of radiation in a submarine are particularly low since there is no radon exposure, no terrestrial gamma-ray exposure, and reduced cosmic-ray exposure. The exposures in space are not so innocuous. Once you leave the Earth's atmosphere, you're bombarded by cosmic rays (primarily protons) and galactic cosmic rays (primarily heavy ions such as iron zipping through space at high energies). This menagerie of radiations may produce untoward (and uncertain) health effects in humans. Since humans aren't exposed routinely to HZE particles, mouse and cellular models are used to get a handle on potential effects. Then you extrapolate from mouse to human. And when you add the differences in dose rate (an experiment might take a few hours whereas going to Mars takes a few years) the uncertainty increases appreciably.

Better comparison populations to assess astronaut risks. It would be valuable to update the study of nuclear submariners (Charpentier 1993) to contribute to the risk assessment models for astronauts, perhaps in combination with other healthy populations such as the Million U.S. Radiation Worker and Veteran study (Bouville 2015). Although the submariner doses are relatively low, the numbers are large, about 85,000, and submariners are more similar to astronauts than the comparison population currently used, i.e., 1945 Japanese atomic-bomb survivors exposed in less than a second and living in deprivation after World War II (NCRP 2014). The important similarities between astronauts and submariners and the million workers are that they are all healthy adult populations exposed chronically to radiation over a period of years. Increasing the accuracy of the risk estimate (for cancer in particular) would reduce the uncertainty and improve the radiation protection guidance for long-term space travel. Why? Current NASA guidance involves limiting the cancer risk to a 3% lifetime increase. To address the multiple uncertainties involved with the risk projection, the actual dose limit is set as the cumulative dose for which the 95% upper confidence limit, not the point estimate, yields a 3% increase in lifetime cancer risk. Thus, even if the risk estimates remained similar, reducing the uncertainty would increase the allowable dose and increase flexibility in missions for both male and female astronauts. Learning of any late-occurring health effects such as dementia among submariners possibly associated with the stresses involved with long voyages in close quarters with minimal interaction with the outside would also be informative.

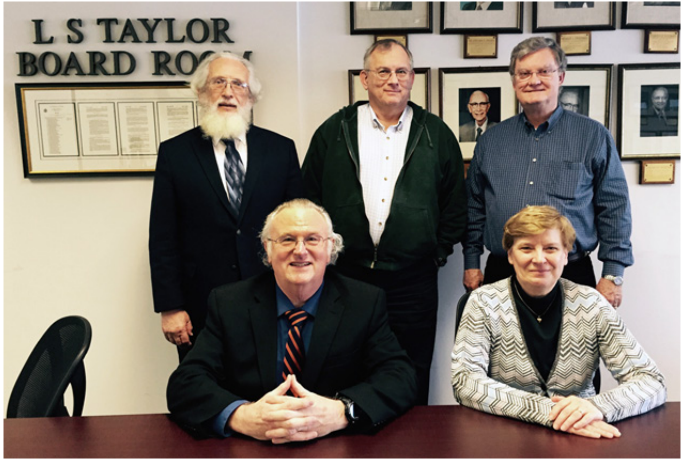
Aside. An ideal comparison group for astronauts in space would be identical twins who are astronauts on Earth. Remarkably, two twin astronauts have agreed to an array of human health evaluation. This March, Scott Kelly will embark for a year on the International Space Station while his twin brother astronaut, Mark, remains on Earth (Time 2014). Now if Einstein's Twin Paradox holds, Scott will return to Earth younger than his twin brother Mark since Scott's biological clock will tick a bit slower because of traveling at a faster rate! However, since Scott will be traveling at International Space Station speed and not light speed, he will return younger but probably only by ~14 milliseconds.

NCRP SC 1-24 on CNS. Overcoming in part the New England snowmageddon, SC 1-24 was able to meet in person and by telephone this January (photo on page 25). The committee is well on its way to completing a commentary on the critical issues surrounding the potential short- and long-term consequences of space radiation on the CNS. Existing human and experimental data are described, research needs outlined, and the groundwork provided for a comprehensive subsequent report (Phase 2). The important topics include:

- *Mechanisms for radiation damage in the CNS.* Mechanisms likely different from those for cancer because DNA damage and changes in cell proliferation may not be critical issues for induction of CNS damage as they are for cancer.
- *Experimental animal research.* Endpoints to consider might relate to both simple and complex human behaviors—not just cognition and memory functions, but also possible post-traumatic-stress-disorder-liklifetimee changes.
- *Human data.* Are there human circumstances on Earth (or under the sea) that might be considered analogues to space for which relevant CNS changes can be evaluated?
- *Integration of data across all biological scales.* An approach is needed to integrate data from cells, experimental animals, and humans, including any relevant epidemiology data, into a coherent model that will facilitate development of risk-projection models.
- *Interactions of radiation with other factors.* Radiation may be modified by other factors in space, such as weightlessness, altered oxygenation, stress, altered sleep patterns, changes in exercise, diet, and more.

NCRP annual meeting is 16–17 March 2015. Last chance to register for "Changing Regulations and Radiation Guidance—What Does the Future Hold?" (no charge to register or attend).

NCRP Scientific Committee 1-24 on Potential CNS Effects From Space Radiation, January 2015, Bethesda, Maryland



Sitting, left to right: John Boice (NCRP) and Kathy Held (Harvard, Massachusetts General Hospital); standing, left to right: Cochair Les Braby (Texas A&M University), Cochair Richard Nowakowski (Florida State University), and Larry Townsend (University of Tennessee); missing (snowbound): James Root (Memorial Sloan Kettering Cancer Center), Marvin Rosenstein (NCRP), Greg Nelson (Loma Linda University), Rudy Tanzi (Harvard, Massachusetts General Hospital), Lee Goldstein (Boston University), Walter Schimmerling (NASA, retired), and Greg Armstrong (St. Jude Children's Research Hospital)